A New Heat Treatment for High Critical Current Nb$_3$Sn Wires

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Introduction
Throughout the development of Internal-Tin Nb$_3$Sn superconducting wires [1], the initial heat treatment conditions have been empirically derived for each wire design. For instance, it is often claimed that a proper Cu-Sn mixing needs to be obtained in order to form high quality Nb$_3$Sn [2]–[4] and it has also been claimed that the formation of voids during wire reaction is detrimental to critical current, $J_c$ [3]–[5]. However, these claims have not been supported by the necessary level of microstructural characterization. High $J_c$ internal Sn strands are becoming increasingly important for the next generation of high field accelerator magnets and it is clear that the complex standard heat treatment schedules are not optimized for the small effective filament diameter ($D_{eff}$) designs that will be required for these magnets. Therefore we have performed the first in-depth exploration and optimization of these heat treatments based on quantitative analysis of the microstructures. We find that for this type of wire, the key process in developing a homogeneous and efficient microstructure is the formation and control of a Sn-Nb-Cu “Nausite” phase membrane around the core components. This new understanding has allowed us to develop heat treatments that have increased $J_c$ values by as much as 26% in small $D_{eff}$ wires.

Experimental - Quench experiments and image analysis
We used partially reacted wires “quenched” at different stages of the heat treatment to study the microstructure at a given point in time (during the heat treatment). Digital image analysis algorithms developed here at the MagLab are used to extract quantitative information from the reaction kinetics.

Results and Discussion
Using the knowledge acquired through the quench experiments and image analysis, we have designed a new heat treatment that takes advantage of the kinetic processes facilitated by the Nausite membrane and we have managed to increase the $J_c$ of the wires significantly. Fig.1 shows the different $J_c$ values at different fields for the same wire at different sizes, comparing the standard heat treatment to the new heat treatment proposed. When tested across several billets we found this heat treatment has the greatest beneficial impact on wires with small $D_{eff}$, as is also the case of Fig.1 (notice the arrows).

Conclusions
The heat treatment schedule for RRP® wires has been significantly improved for the so-called “mixing” dwells, producing a 13% increase in 15 T $J_c$ across several wire billets at various sizes—while maintaining excellent Cu RRR. The $J_c$ enhancement increases as the designed $d_{eff}$ decreases and will therefore be of great benefit to future high field accelerator magnets.

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References